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RADIO FREQUENCY DATA

COMMUNICATION APPLICATIONS

IN THE CONSTRUCTION INDUSTRY

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By

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July, 1989

Division of Construction Engineering and Management
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RADIO FREQUENCY DATA COMMUNICATION APPLICATIONS IN THE CONSTRUCTION INDUSTRY

A Special Research Problem
Presented to

The Faculty of the Construction
Engineering and Management Program
Purdue University

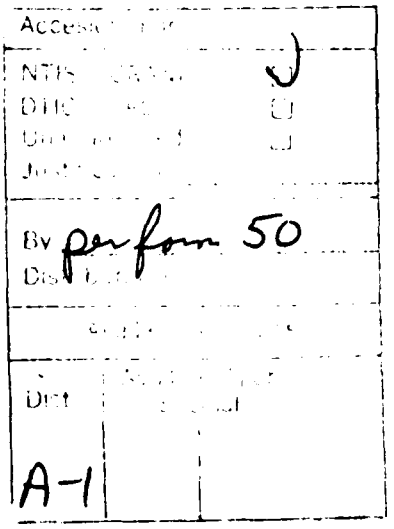
by

Michael N. Rieger

In Partial Fulfillment
of the Requirements for the Degree of
Master of Science in Civil Engineering

26 July 1989

Approved:



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ABSTRACT

Bar codes have gained increased importance in many industries due to their proven cost savings. By 1987 the bar code market in the U. S. had grown to $740 million. They have been used to track overnight mail packages, mark computer circuit boards, track tools and apparels, trace blueprint status, and numerous other applications.

Bar codes have traditionally been used as a passive identification symbol on items. The symbol is read by a scanner which stores the information encoded by the symbol until it can be downloaded into a computer. However, bar codes have recently been combined with radio frequency equipment to add an interactive, real-time dimension. Users can now read from and write to a computer database from remote locations without any physical link between the operator and computer. And when integrated circuits are substituted for the bar code symbol, hundreds and even thousands of bits of information can be stored in and read from the chip. This new technology is known as radio frequency data communication.

This paper discusses how radio frequency data communication systems are being used by other industries, explains each of the hardware and software components that are required for a complete system, describes some of the potential construction uses, and outlines some recommended considerations for implementing a RFDC system.

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CHAPTER I

BACKGROUND

In today's highly competitive construction market, timely access to accurate information has become an essential ingredient for successful businesses. In recognition of its ability to satisfy this requirement, companies are increasing turning to automatic identification systems.

While this trend has only begun in construction, other industries have utilized this technology for more than 20 years. One system, bar codes, have become the most widely used since their adoption by a Kroger's supermarket in 1967. In recognition of the importance of bar codes and the savings that could be realized by them, the Department of Defense established the Logistics Applications of Automated Marking and Reading Symbols (LOGMARS) commission which resulted in the requirement that bar codes be applied on all items sold to the Department of Defense. Major industries which have adopted the use of bar codes include automotive, aerospace, utilities, healthcare, and to a limited extent the construction industry. Uses in the construction industry have included the following functions (Bell and McCullouch 1988): material takeoffs, field material control, warehouse inventory & maintenance, tool & consumable issue, timekeeping & cost engineering, purchasing

& accounting, scheduling, document control, incident reporting, and office operations.

While the use of bar codes has steadily grown into an over $1 billion per year industry, other systems have also gained increased usage. These systems include radio frequency identification, optical character recognition, voice data entry, radio frequency data communication, magnetic stripe and smart cards. A description of each of these systems follows.

Bar Code Scanning. A system of horizontal, wide and narrow, bars and spaces which encode numbers and often letters into a symbol which is placed on a tag or label and used to identify products. It is highly versatile, extremely accurate, and faster to read than most identification systems.

Radio Frequency Identification. Uses bi-directional radio transmissions to interchange information. Typically consists of an identification tag or transponder, an antenna and a transmitter/reader. Upon activation the tag transmits information which is picked up by the antenna and sends it to the reader. This information can then be downloaded into a computer via a hardwire link at a later time. The information capacity of tags varies from as little as one character to an entire database.

Optical Character Recognition (OCR). This system features human readable numbers or letters that are scanned by light sources. Once a successful scan is made, the information can be passed to a computer. Its main advantage is the human recognizable feature. However, its read rates are significantly slower than bar codes. An example of OCR use is the characters which are on bank checks.

Voice Data Entry. This system uses pattern recognition of words in a preprogrammed library. The operator's spoken words are converted into electronic impulses which are then fed into a computer. A response occurs when spoken words match the words stored in a database. The database is formed from words that the user stores in the database. Since the words are spoken into a microphone (normally on a headset), the user's hands are free to perform other operations. In implementing this system, the following variables must be considered (Materials Handling Engineering, Sept '88): accuracy, speaking rate, noise tolerance, type of input device, speaker limitations, vocabulary size and structure of language.

Radio Frequency Data Communication. This system utilizes hand-held or vehicle mounted terminals which, when combined with bar code symbol systems, radio frequency identification systems, or voice data entry,

are able to interchange information between the user and the host computer on an interactive basis. Since a radio link is used for information exchange, the operator is able to immediately query the computer database without being physically connected to the computer. It is this ability that differentiates RFDC systems from simple radio frequency identification systems.

Magnetic Stripe. This system consists of information encoded onto a media using low or high energy charges. These charges can then be read by a decoder which translates them into numbers or letters for identification by a computer. It is most often used on credit cards, bank cards, and employee badges.

Smart Cards. Smart cards are plastic, wallet size cards with embedded, programmable microchips that are essentially a database. They are read when they are passed through a scanner which records the information on the cards.

CHAPTER II

PROJECT DESCRIPTION

Statement of the Problem

Automatic identification systems are a proven method to accurately speed the access to and transfer of information. The most common system, bar codes, have found widespread use in automotive, aerospace, supermarket and healthcare industries and to a limited degree in the construction industry. However, simple bar code systems have one major drawback: real-time interaction with a computer database can only be done with a hard-wired link to the computer. Project sites and warehouses are seldom able to meet this requirement. Radio frequency data communication (RFDC) systems, which often use bar codes as part of the overall system, eliminate this problem by interfacing with the computer via radio links. Thus, RFDC systems can supplement a company's bar code system in order to achieve greater benefits. What is a radio frequency data communication system? How have other companies used them? What equipment is required and how much does it cost? How can it be applied to the construction industry? This study will provide insight into these perplexing questions.

Objectives

The objective of this study is to stimulate the consideration of the use of radio frequency data communication systems technology by the construction industry. To achieve this goal the following subject areas will be discussed. First, the use of RFDC equipment by other industries will be examined. This includes systems for warehouses in which operators are able to remotely query computer databases for locations to store materials and then later retrieve them, for airport gates that automatically open when authorized vehicles approach, and systems that control employee access to secure areas. Next, system hardware and software will be described, cost ranges provided and physical limitations discussed. Potential construction uses including material receipt/issue & cost control, steel erection, warranty & maintenance of installed equipment, tool control, material movement tracking, vehicle maintenance, worker identification, system component identification, and quality control will be discussed. In order to provide an understanding of how to establish a RFDC system, implementation considerations will be provided. This includes how to form the project team, evaluate which functions to include in the system, select equipment and vendors, startup the system, and train employees. Finally, some ideas for future research in the use of RFDC systems in the construction industry will be discussed.

Methodology

This study is an independent research project in partial fulfillment of the requirements for a Master's Degree in Construction Management at Purdue University. It was completed through a review of current journal articles on bar codes in automotive, aerospace, manufacturing, and construction industries; standards and studies published by the Department of Defense; and manufacturers' literature. Also, since automatic identification systems and RFDC systems in particular are a rapidly changing technology, several manufacturers' representatives were contacted to provide current data and answer questions about their specific systems. Finally, a review of books and journal articles on the construction industry was conducted to determine how companies frequently complete the tasks discussed in the chapter on construction applications.

CHAPTER III

RADIO FREQUENCY DATA COMMUNICATION & BAR CODE USE IN OTHER INDUSTRIES

Although the construction industry has not implemented radio frequency data communication systems, many industries including the automotive, aerospace, telecommunications, and aluminum have implemented systems. Factory applications include (Quinlan, Sept '85): tracking work-in-process & hand tools, managing toolroom inventories & tools in automated machining, maintaining security of data, updating production schedules, monitoring workstation productivity & machine usage, scheduling tool and machine maintenance or replacement, providing traceability of parts, monitoring quality levels and trends, reducing product warranty and recovery costs, automatically identifying parts, pinpointing individual assignments, improving management information systems, and monitoring worker time and attendance. The following sections describe a few of the systems which are presently in operation.

AutoCon

AutoCon is a General Motors distribution warehouse which coordinates movements of material from three manufacturing divisions in the Dayton, Ohio area to more than 30 GM assembly plants in the U. S. and Canada. The

330,000 SF warehouse receives and distributes about 10 million pounds of material each week in auto standard 31" x 51" wire baskets. Shipments are made by both trucks and railcars. GM estimates that the RFDC system saves $6 million per year in transportation costs alone. Savings are achieved because less-than-full trailer loads are eliminated, shipments are faster and more timely, and more accurate inventories are kept.

The system works as follows: shipments are made from the manufacturer's plant to AutoCon's warehouse dock with four bar codes on each container. These identify the container's serial number, part number, supplier code, and quantity. When the load leaves the manufacturer's plant this information is scanned and entered into a GM mainframe computer located 15 miles from AutoCon. As the load is received at AutoCon's warehouse, a lift truck operator scans the bar code serial number with a hand-held laser to identify the contents. Since the scanner is linked to the mainframe computer by a radio frequency and telephone link, acknowledgement of receipt of load is made in two to four seconds. The forklift's terminal then directs the operator to distribute the load to another location on the dock for reloading or to a high bay storage area. The specific warehouse location is determined by how soon the material must be shipped out. If the material is to be stored, the terminal will direct the operator to load the shipment on

one of 16 automatic guided vehicles. The system's software will direct the AGV to a location of similar material. Upon arrival at that location another forklift operator will scan the bar code to determine the storage location and then inform the computer when the material has finally been stored.

When retrieving the material, the process is reversed. After entering a specific function key on a terminal, the computer will direct the forklift operator to the storage location. He will then load the material on an AGV which will take the material to the dock. The person loading the truck will scan the load, his ID badge, and a bar code time clock. The terminal will inform him about the container's weight so that he can properly load the truck.

The software for this system was developed by GM.

Source: Witt, 1986

GM Parts Warehouse

Another General Motors plant, which is located in Pontiac, Michigan, also uses a radio frequency system. This program involves the shipment of about 2000 high volume parts such as filters, spark plugs and fuel pumps directly to dealers, thus bypassing regional parts distribution centers. In return for minimum orders, dealers are promised discounts, high availability, accurate shipments, and timely

delivery. With this system GM was able to go from a manual, pushcart operation to a highly automated system.

The operation works as follows: When a pallet load is received a bar code identification tag is placed on it. Forklift operators then either key in the bar code on the forklift's terminal or scan the bar code. The terminal, which is connected to a computer via a radio frequency link, directs the operator to a storage location. After the load has been placed on the storage rack, the operator verifies the location by scanning the load's tag and a label on the rack.

When retrieving items, an operator on a load car inserts into a holder on the car a roll of bar code labels for the items to be retrieved. A scanner on the car reads the label and directs the car to the storage location. Another scanner on the car verifies the location, turns on lights to illuminate the rack and sends a signal to the terminal on the car to notify the operator what to retrieve. When the item is loaded on the car, a label is automatically applied to the carton. After the appropriate numbers of items at that location have been retrieved, the car moves on to the next location. After all material has been picked up the car takes the load to a sortation system. There another scanner sorts the orders for shipment.

Source: Witt, 1989

AT&T Atlanta

This plant also uses its RFDC system for inventory control. The plant manufacturers copper wires and cables as well as optical fiber cables. Raw materials received each year include 75 million pounds of copper, 36 million pounds of plastics, 10 million pounds of steel, and 4 million pounds of aluminum. The system tracks material location in four storerooms plus exterior areas. Twenty hand-held and forklift mounted radio frequency terminals are used along with an antenna to ensure elimination of interferences from shop motors, metal racks, shelving, and security enclosures.

The system operates as follows: Upon receipt of material at the dock, pallets are labeled with a bar code. At the same time the shipping documents are sent to the receiving office where the information is entered into a computer. When the dockworker keys the pallets contents into a mobile terminal, a check is made to verify the accuracy of this information and the shipping data. Next, a forklift operator picks up the material and enters into the forklift's terminal the information on the pallet. The computer directs the operator to a storage area. As the operator puts the material in the storage location he scans a bar code on the rack at that location to ensure correct placement and to update the database.

With this system inventory accuracy was increased to 99% and 10% of the warehouse's inventory can be verified

each week without closing storerooms. The average time to unload a truck has been reduced from 90 minutes to 10 minutes. Loss of production time due to inventory shortages or losses has been reduced to 0.5%. Inventory levels have not changed, but production has doubled. Payback on the system was estimated to be three months.

The system was implemented in phases. It was first a stand-alone system for receipts. Then two storerooms were added. Finally, purchasing, accounts receivable, and production control functions were incorporated. Selection of the system was made by representatives from engineering, shipping/receiving, production control, purchasing and accounting.

Source: Dunn, 1987.

Kaiser Aluminum & Chemical Company

Kaiser Aluminum & Chemical Company, Spokane, Washington, uses a RFDC system to track its 5000 ingot inventory of metals over a 65-acre, indoors and outdoors plant. They do this by attaching a glue-backed strip of bar coded plastic on each ingot. This label can withstand temperatures of 300-400^{o}F. Also, dirt, grease, oil and cold winter temperatures do not affect scanning of the labels.

Under the former system, the ingots were marked in hand with hot crayons. However, because these markings were not always clear, locating particular ingots often resulted in

costly searches, misshipments were made, and production delayed.

With the new system, laser scanners are used to scan the bar code at each step in the production process. This information is fed to the plant's mainframe computer for tracking the exact location of each ingot. The bar code reader can be either hand-held or vehicle mounted and is capable of operating without interruption outdoors. It also has an 80 character alphanumeric keyboard. This is used to enter information if the bar code cannot be successfully scanned by the laser.

The result is that ingot inventory has been reduced from 4000 to less than 1000. Metal losses have been reduced significantly. Now the plant managers can determine each ingot's exact location at any time in the production process.

Source: Metal Producing, 1987.

Washington National Airport

RF tags and equipment are being used at Washington's National Airport to control access to parking lots by shuttle buses, management and maintenance vehicles, airport fire department trucks and security vehicles.

The former system used magnetic stripe cards which the vehicle operator would insert into a reader to gain access. However, due to the widely varying size of vehicles, a

location that was easy for one vehicle operator to reach could not be reach by others. This resulted in delays and damage to the equipment. Also, breach of security from lost badges was a problem.

With the new system, RF tags are permanently attached to each vehicle. This eliminates the problem of loss of tags and unauthorized use since the tag can easily be reprogrammed if stolen. As the vehicle approaches a gate, the tag is read and a signal is sent to the gate controller to automatically open if access is granted. The tag can be read at speeds over 40 mph and distances of over 36 inches. A printer records the time and date of access, location, vehicle description, and whether access was granted or denied. A total of 32,000 vehicles can be monitored. **Source: "Airport Tags Solve Access Control Troubles At Airport Parking Lots", 1988.**

Shaw's Supermarkets

Shaw's Supermarkets has installed a magnetic card access system for employees at its New England stores. Each employee is issued the card which the employee uses to gain entrance into various secure locations within the supermarkets. Since a computer database is used to keep track of who has what cards, updating the system when new employees are hired, former employees leave, or cards are lost takes just a few minutes. The system installed

accommodates up to 2400 cards and 256 readers. It is programmed to allow employee access only during hours when the employee is scheduled to work and into areas in which he is permitted. A printer tracks each accepted or denied access. If access is granted, the controlled door is automatically unlocked.

Source: "Supermarket Adds Electronic Access Control", 1988.

Martin Marietta Electronic & Missile Group

Martin Marietta is using a RFDC system in conjunction with an automatic storage and retrieval system (AS/RS) at a warehouse in Orlando, Florida. The system performs on-line material tracking and material handling personnel dispatching. A total of over 35,000 parts are tracked.

Under the old manual system, material retrievers found material with a 25 character alphanumeric designation on a hand printed sheet. Since a one character mistake would result in the picking of the wrong material, there was a high likelihood of human error.

Under the new system, a bar code label is attached to containers holding each part. The system tells the material retriever where to find the material, confirms that he is in the correct location once he gets there, confirms he has picked the correct material, and updates the inventory database once the pick is completed. Communication to the

host computer is via a radio link and uses simple ASCII commands.

Reported benefits of the system include:

- "Better inventory utilization by providing accurate real-time inventory information. Stock-outs and late shipments can be avoided and the quantity of physical inventory reduced.
- The elimination of move tickets, pick lists, and other paperwork. The host computer directs material movement.
- Effective space allocation by identifying vacant space and assigning specific goods as they are received. Dynamic space allocation reduces or eliminates the need for fixed storage locations.
- Improved data entry accuracy by automatically entering information into the host data base via bar code scanner or raised alphanumeric keyboard.
- Enhanced inventory accuracy through real-time cycle counting, as inventory shut-downs are avoided.
- Reduced communication delays for both the terminal operator and for the computer with transaction times that are typically less than one second."

Source: "Missile Group Shoots For Inventory Accuracy", 1988.

CHAPTER IV

HARDWARE AND SOFTWARE REQUIREMENTS

The key components which make up a radio frequency data communication system are: a bar code label/transponder, a reader, a computer interface unit, and a computer which uses application specific software to decode/encode the messages received/sent. Figure 1 provides a schematic layout of how these items are linked together. These items are discussed in detail in the following sections.

Bar Code Label/Transponder.

Bar code labels and transponders encode information about the product to which they are attached/imprinted. The two most common forms of this component are the bar code symbol on a tag or label and the transponder. The major capability difference between these components is that information can only be read from a bar code symbol whereas the transponder normally has the capability to be read from and written to.

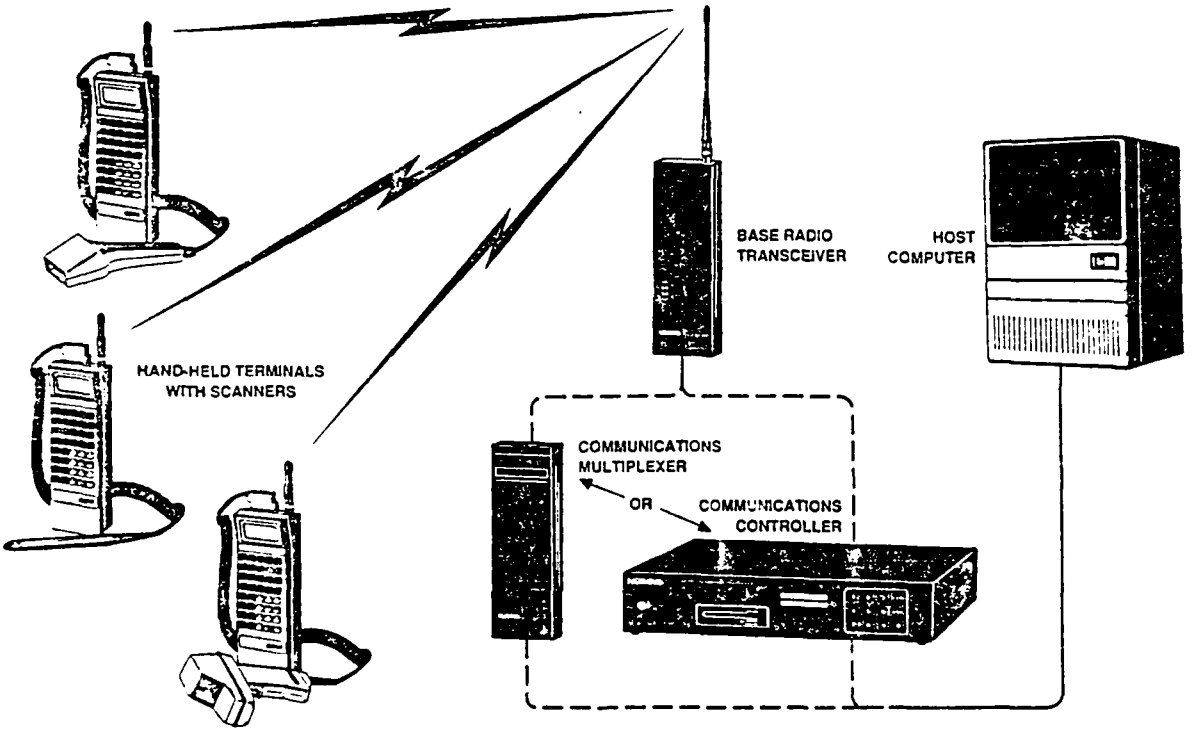
Bar Codes.

If a bar code symbol is used, the type of symbol, media to which the symbol is applied, bar code scanner and printing method must be selected. Requirements for these items are as follows.

Figure 1

Radio Frequency Data Communications

System Layout



Source: Norand Data Systems Manufacturer's Brochure

1. **Bar code symbol.** Bar code symbols encode information about the product. The user selects what information is to be encoded, and the only limitation on the amount of information is the size of the tag/product.

Bar code symbols are simply alternating parallel bars and spaces, some wide and some narrow. The ratio of the size of narrow to wide bars is fixed and normally in the range of 1:2-3. A combination of these narrow and wide spaces and bars constitute a number, letter, or graphics symbol. By including start and stop symbols at the beginning and end of a group of characters, scanning can be performed either forwards or backwards, thus eliminating the need for the operator to check scanning direction.

There are numerous codes which are currently being used. The more popular ones include UPC which is used by supermarkets, Interleaved 2 of 5 which is used for warehouse control, Codabar which is used by libraries and for medical applications, and Code 39 (also referred to as Code 3 of 9). The primary differences between the codes include the number of characters (letters and numbers) which are encoded and density (i.e., number of characters per inch or cpi).

Although any of these codes can be used, and most scanners can read several different types of codes, the

overwhelming choice of industrial users, including construction, is the Code 39 symbology. The primary reason for this is that Code 39 includes all ASCII characters and thus is one of the most versatile. Therefore, unless an overriding factor requires otherwise, this code should be used by construction companies to maintain uniformity and thus allow for intercompany exchanges. Code 39 gets its name from having each alphanumeric character consist of 9 alternating light and dark bars, 3 of which are wide and the rest narrow. An example of Code 39 can be seen in Figure 2 and the complete listing of the code's symbols in Table 1. Code 39 bar code width varies from 1.7 (low density) to 9.4 (high density) characters per inch.

Why use bar codes? Bar codes are important because they are inexpensive, easily produced & scanned, result in labor savings, reduce data entry errors, and shorten the delays in getting information to the manager when he needs it. Entering data into a computer is 2 to 12 times faster with bar codes than with standard keypunch entries. Data entered by hand typically results in one error per 300 entries. A test of bar codes by the Department of the Defense found just 4 errors in 13,517,832 entries. And with bar codes, information obtained in the field or warehouse

Figure 2*

Typical Code 39 Symbol

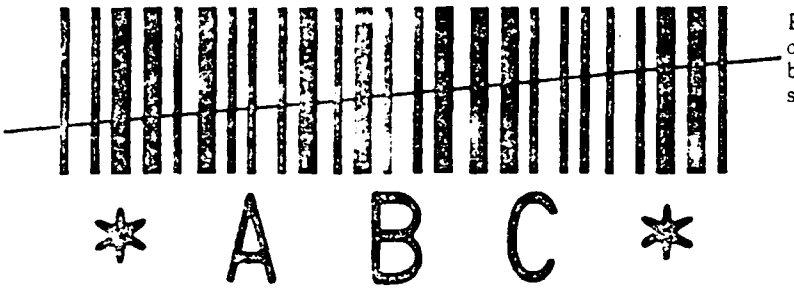


Table 1*

Code 39 Configuration

CHAR.	PATTERN	BARS	SPACES	CHAR.	PATTERN	BARS	SPACES
1		10001	0100	'		11000	0001
2		01001	0100	N		00101	0001
3		11000	0100	O		10100	0001
4		00101	0100	P		01100	0001
5		10100	0100	Q		00011	0001
6		01100	0100	R		10010	0001
7		00011	0100	S		01010	0001
8		10010	0100	T		00110	0001
9		01010	0100	U		10001	1000
0		00110	0100	V		01001	1000
A		10001	0010	W		11000	1000
B		01001	0010	X		00101	1000
C		11000	0010	Y		10100	1000
D		00101	0010	Z		01100	1000
E		10100	0010	-		00011	1000
F		01100	0010	.		10010	1000
G		00011	0010	SPACE		01010	1000
H		10010	0010	*		00110	1000
I		01010	0010	$		00000	1110
J		00110	0010	/		00000	1101
K		10001	0001	+		00000	1011
L		01001	0001	%		00000	0111

* Source: Allais 1985

can be immediately fed into a computer via a modem. The manager can analyze and manipulate the information; then take appropriate action to alleviate any problems.

2. **Tag/Label.** Tags and labels are the media to which bar code symbols are applied. They include metal tags, labels, and the item to be bar coded itself. Metal tags are normally attached to the item; labels can be attached as tags or permanently glued to the item to be identified. The factors which should be considered when deciding which method to use are the following:

a. Labels are generally made out of paper. Thus, they can be quickly and economically produced by many different means. However, they are not as durable as metal tags.

b. If the code will be subject to adverse conditions such as dirt, grease, temperature extremes, weather or frequent scanning (>50 times), either a tag should be used or the label must be protected by plastic laminate or lacquer spray.

c. Permanently applied labels can only be glued to a smooth surface. Many construction items do not exhibit this characteristic.

d. If the code is applied to construction materials and will be evident when the materials

have been installed, problems with aesthetics should be considered.

e. If the time the code will be required on the item is limited, and reuse is not feasible, labels should generally be selected since they are much cheaper to produce than tags.

f. Metal tags, which are normally etched with the code, are extremely durable. However, mass production of the tags, especially on-site, is difficult and thus their cost is much higher than labels. A significant advantage of metal tags in construction is that they can be easily reused.

g. Direct printing is generally performed by the manufacturer. This could be an ink imprint or a laser etch. However, few, if any, manufacturers of construction items presently bar code their items. It would be especially beneficial if this was done with items which cannot be feasibly tagged or labeled (i.e., tools).

A combination of methods will normally be required for most construction applications. For instance, tools may be permanently marked whereas construction material may simply have the tag or label attached to it.

3. Scanners. Scanners are used to transfer the information contained in the bar code symbol to the

reader. There are three primary types of scanners: stationary fixed beam, stationary moving beam and hand-held. Fixed beam scanners send a beam of light perpendicular to the object to be scanned. As the item moves by (normally on a conveyer), the bar code symbol passes through the beam and is read. Moving beam scanners send a continuous, moving beam of light over a fixed area at a rate of up to 150 scans per second (Quinlan, 1985). A bar code symbol passing through the area will be scanned several times. This greatly reduces scanning errors. However, moving beam scanners cost several times more than fixed beam scanners. With a hand-held scanner, the bar code is read when the operator passes the scanner's light beam over the code.

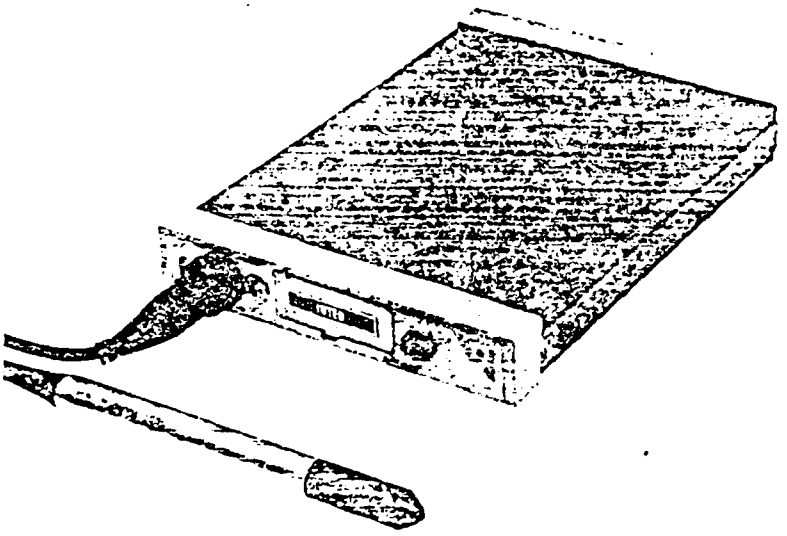
There are two types of hand-held scanners: the wand and laser. A wand scanner uses a light emitting diode (LED) to send out a continuous, fixed beam of light. Laser scanners emit a moving beam of light. Figures 3 and 4 illustrate both types of hand-held scanners.

The principle advantages of the wands are their weight (1.6 vs 16 oz.) and cost (about $43 vs $395 to $773). However, lasers offer the following advantages (Dilling, 1984):

a. Scanning is non-contact, thus avoiding label damage and problems with water, grease, oil, etc.

Figure 3*

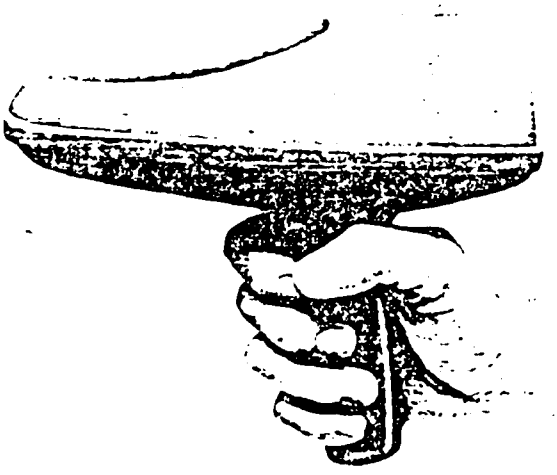
Hand-held Scanner (w/reader)



* Source: Dilling, 1984

Figure 4**

Laser Scanner



** Source: Baker, 1985

b. Multiple scanning attempts per pass (10 to 150 per second) result in more chances to read the code, thus reducing read errors. Wands only make one scan attempt per pass.

c. Depth of field (the distance from the scanner to the code) is up to 23 inches compared to 0.012 inches or less for wands, thus eliminating need for virtual contact with code. This is especially important if the bar code is covered with a protective laminate or when scanning rough, uneven, curved and flexible surfaces.

If it is decided to use a wand, a closed-tip type should be chosen in order to eliminate the problem of the tip becoming clogged with dirt and other debris common on jobsites and in warehouses.

Since most construction applications require that the scanner be able to move around the jobsite and warehouse, the principle scanners which would be used by construction companies are the hand-held scanners. These scanners can perform the following functions (Dilling, 1984): enter shipping data on-line to a mini computer, check tools in & out, report production status, report quality assurance status, track shop progress on a job, confirm warehouse storage location, record physical inventory, track shipments, and collect labor utilization.

4. **Printer.** Printers are used to generate the bar code symbol on the tag, label or item itself. There are a myriad of printers which may be selected, including (Baker, 1985): serial (formed-font) impact, dot or square matrix, thermal, ink-jet, photostatic, photographic, and laser. Prices vary from $1400 (thermal) to $5800 (serial impact). Since the selection of the printer will be dependent on what method of bar code labeling is chosen (i.e., tag, label, direct imprint), this must be done first. One important factor to also consider in printer selection is how and when (on-site vs off-site) the printing will be performed. Low volume, convenience, and internal control are factors that favor on-site, in-house printing. Low cost and support, especially during the start-up phase, favor off-site printing.

Some of the printer selection factors include (Baker, 1985 and Allais, 1985):

a. Formed-font printers can consistently produce high quality labels. They have the flexibility to produce unique and sequentially numbered labels. Also, higher density (up to 9.4 characters per inch) printing is achieved, thus decreasing required label size. Individual labels can be dispensed or even applied directly to the item to be marked. This versatility has won the

Department of Defense's endorsement. However, these printers cost more.

b. Matrix printers are some of the most widely used printers since many companies already use them for other computer applications. Since they can easily produce both text and graphics they are particularly suitable for in-house printing. Although almost any computer dot matrix printer can produce bar code labels, quality can be a significant problem. While the label produced may appear to be satisfactory to the human eye, it may not be scannable. Also, the ribbons used may quickly wear out and thus degrade the quality of the bar code. Thus, only higher quality printers should be considered and extensive testing should be completed. Dot matrix printers generally produce low density labels (4.2 characters per inch) and single label printing normally results in loss of several blank labels.

c. Laser and ink-jet printers are equally capable of printing directly on the material to be coded or on labels. They are more economical for high volume printing. However, most construction applications would not require this high volume.

d. Thermal printing is generally the cheapest type. It is slower than other printers (20 vs 180

labels/minute for impact printer); however, few construction applications require high speed printing. Density is intermediate (7 characters per inch) and quality is excellent. Individual label dispensing is available.

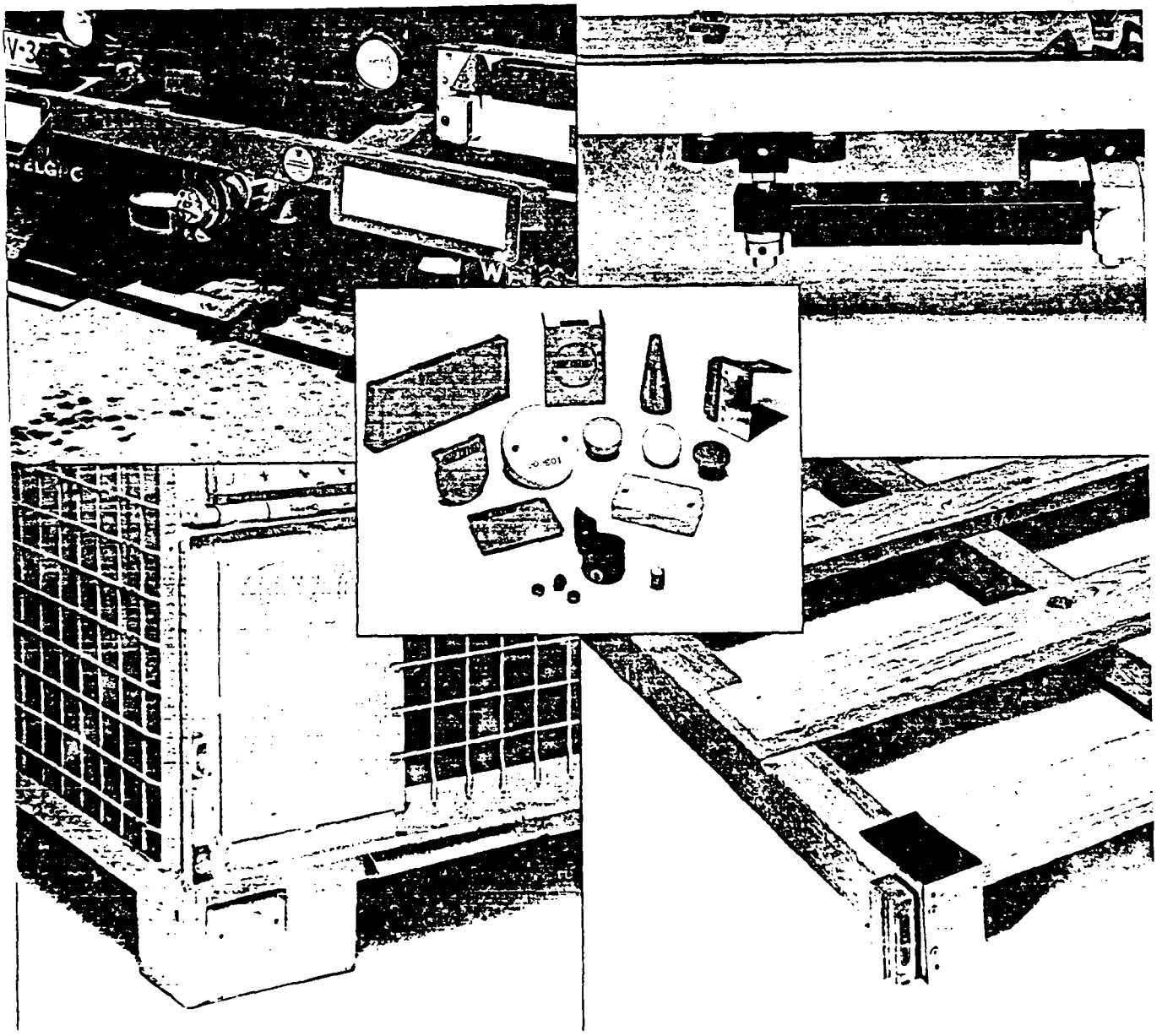
Transponders.

Transponders contain an antenna and circuitry that store information and when activated transmit the information via an electronic signal to the reader. Transponder sizes range from a small slug to the size of a credit card to 3" x 8" (American Machinist, 1987). Figure 5 shows several different types of transponders. The smaller device is used when the range to the reader is small, and speed (if motion of the transponder is required) is low. The larger transponders can be read at distances up to 25 feet and at speeds of over 120 mph (American Machinist, 1987).

Transponders can be either passive or active. Upon activation by a reader passive tags simply pass preprogrammed information to the reader as long as it is within range. This information can be programmed either by the supplier or on-site. However, once programmed, the information does not change until reprogrammed. This cannot be done by the reader. Memory size can vary from one bit, for simple item presence verification, to 128 bits for item identification (American Machinist, 1987). Active tags can

Figure 5

Typical Transponders



Source: NEDAP, GIS Manufacturer's Brochure

be both read from and written to. Memory capacity can be as large as 32 KB (Bursky, 1988); thus they are essentially a portable database.

Transponders can be placed virtually anywhere. In manufacturing they are most frequently placed on pallets, vehicles, and other items in motion. They can withstand temperature extremes of -400°F to 4000°F and their cost ranges from $5 to $200 (American Machinist, 1987). This wide cost range is due to varying capabilities of tags supplied by manufacturers. Internal batteries allow storage of information for up to 10 years without loss of memory and error rates can be less than 1 in 10^{14} readings (Stefanides, 1987).

Reader

Readers are known by many other names including data collection device, radio frequency unit, portable data terminal, and radio data terminal. Regardless of what they are called they all gather data by one of two basic methods which depend on whether a bar code symbol or transponder is being read. If a symbol is being read, the reader will receive and process the information which has been gathered by the scanner. The scanner and reader are hardwired together. If a transponder is being read, the information is transferred to the reader via a radio frequency link. In either case the reader will then transfer the information to

the computer interface unit via a radio frequency link. It is this capability to operate without being physically attached to a computer that allows the user to utilize the equipment virtually anywhere. This ability is a requirement in most construction applications.

Readers exhibit the following characteristics:

1. When reading bar code symbols most readers can receive information from either a wand or a laser scanner. It is the reader which actually "reads" the bar code and within about 15 to 25 milliseconds informs the user if the bar code has been read by sounding a "beep". No sound is heard if the bar code is not read. Readings may not occur if the scanner did not pass through the entire bar code, if the user bumped something during scanning, there was a rapid change in velocity during scanning, or due to a poorly printed bar code (Dilling, 1984).
2. Readers can be hand-held, mounted on a vehicle such as a forklift, or positioned at a location near where the transponder will pass.
3. Readers have displays which can display 64 to 320 characters of information, depending on the manufacturer and model. The size, sharpness and readability of the displays also varies and can be selected based on the operating environment.

4. Most readers can read all major bar code symbologies including Code 39, Interleaved 2 of 5, UPC, Code 128, Plessey, and Codabar.

5. All readers have keyboards. Some have as few as 31 keys while others have 62, including full alpha-numeric capability, 40 function keys, numeric keyboard, and color coded keys. Either QWERTY or simple alphabet (ABCDEF) layouts are available on some models.

6. Weight ranges from as little as 2 pounds for hand-held readers up to 14 pounds for forklift-mounted terminals. Hand-held readers are about 2" x 4" x 9" in size and forklift-mounted terminals are about 4" x 7" x 13".

7. Memory capacities range from as few as 8 KB to as much as 1 MB. Thus, immediate transmission of gathered information to the host computer is not required.

8. Operating temperature ranges are generally +140^{o}F to 1200^{o}F.

9. Internal batteries allow 8 to 10 hours of continuous use without recharging. Recharging can generally be done overnight.

10. The cost of hand-held readers is about $2500 to $3500. Vehicle-mounted terminals cost about $4400.

11. Data transmission rate is 1200 to 9600 baud (120 to 960 characters per second).

12. Some readers also allow input by voice transmission and magnetic stripe readers.

13. Printers and audio speakers may be attached as accessories.

Computer Interface Unit

Computer interface units are also known as base stations, control units, and communications controllers. They are normally hardwired to the computer and thus located near it. They can also be linked to a computer with a modem. They provide the link between the reader and the computer. Information is exchanged between the computer interface unit and the reader via a radio frequency link.

Computer interface units have the following characteristics:

1. The maximum distance between the reader and the unit varies from 1000 feet to 3 miles or more depending on the manufacturer, operating frequency and obstructions. While obstructions include firewalls, concrete, and steel, even these materials can be penetrated to some extent. The range increases with lower frequencies; however, information exchange is faster at higher frequencies. The use of antennas will also help to increase the operating range. These factors make it imperative that the equipment supplier be consulted when determining where to locate the reader and

computer interface unit. Virtually all suppliers provide this service when installing the equipment. If extended distances prevent locating the computer interface unit where it can be directly linked to the computer, then the link can be made with a modem.

2. Most units can support many (up to 64) readers at one time.

3. Some units can only send/receive signals over one channel, others as many as 64 channels. Single or multiple computers can be supported, depending on manufacturer and model.

4. Weight is about 2 to 4 pounds and size is about 2" x 6" x 14".

5. Prices range from $1600 to $5100. (The manufacturer of the lower priced model has the higher prices for readers.)

6. Units have a signal detection feature which allows it to exchange information only with the reader which originally sent the signal. This prevents confusion with other readers which may be transmitting information at the same time.

Computer/Software

Almost all computer interface units connect to the host computer through RS-232 ports. Thus, any AT/XT computer can act as the host. Information is sent in standard ASCII

characters which can be read by most software packages. Ashton-Tate's DBase III+/IV is often used.

As discussed by Schwind, 1989, there are five ways to develop software packages to run a company's RFDC system. These are discussed below:

1. Determine what hardware you require and which manufacturers can provide this equipment. Next, select one of the manufacturers to supply your equipment. Work with this manufacturer to develop the software. He may provide software that he has previously developed and modify it to fit your application or he may recommend a consultant who can write the custom software and install the hardware. The manufacturer may also work with your own programmers to customize his software.

2. A software supplier or consultant may be hired directly by you. He will normally provide a standard package and adapt it for your use. He can also often provide complete warehouse management packages, the RFDC system being only one part.

3. Buy a whole package (hardware and software) from a hardware vendor. This can be the fastest way to get a system operational, but it may not suit your company's exact needs.

4. You can hire a systems integrator who will recommend hardware and software suppliers. They may even help in

the development and execution of contracts with these vendors.

5. You can develop the software in-house. However, it is unlikely that in-house programmers will have the necessary technological background to do this.

CHAPTER V

POTENTIAL CONSTRUCTION USES

There are several applications of RFDC systems that would provide benefits to the construction industry. The following sections detail a few of these potential uses.

Material Receipt, Issue and Cost Control

This is the largest potential application and should be one of the first analyzed by any company considering the use of a RFDC system. It should be set up similar to the systems which were described in Chapter III, Uses In Other Industries.

Specifically, the system would work as follows. All materials handled by the company would be bar coded. Since few suppliers of construction materials presently do this, either the company would have to provide the labels to the vendors for attachment to the materials or the company could put them on after receipt of the materials. When a shipment of materials is received, the bar codes would be scanned and the reader would inform the warehouseman where to store the materials. The computer's database would simultaneously be updated. Thus, a check or report of the current status of material procurement could easily be made at any time. Also, it could quickly be determined if the shipment received was for the exact materials and quantities ordered.

When materials are needed, their location would quickly be determined by querying the computer. As the warehouseman gets to the location, he would quickly check that the correct material is being retrieved by scanning a bar code on the bin location or the material itself. At the same time the computer database would again be updated. By scanning the material recipient's badge, a confirmation of authorization to received materials would also be made.

Thus, this system would help maintain a current database of material status, determine material storage locations and direct warehousemen to those locations, and ensure that only authorized personnel are issued materials.

Steel Erection

One of the biggest potential problems during steel erection is locating the correct piece of steel to lift into place when it is needed. A RFDC system could help alleviate this problem as well as others associated with the erection and inspection process.

First, the fabricator would attach a bar codes to each piece of steel, identifying what piece it is, where it goes, what direction (if pertinent) it should be placed in, the location of the lifting points and what angles, splices, etc., need to be attached to it. By maintaining a database of what pieces have been completed, the fabricator could quickly provide the construction contractor with a status

report. When a shipment is made by the fabricator, a scanning of these bar codes would ensure that the correct pieces are being shipped. When the shipment is received by the project, another check of the shipment would be performed and the storage location determined. Then, when erection starts, the storage location of each piece would quickly be found by querying the database. When the piece is located, scanning the bar code on it would confirm that it is the correct one, any required splices, etc., made, and lifting cables attached at the correct points. If the crane operator is also hooked up to the system, he would be able to quickly determine what load he is lifting. Since each piece of steel would be scanned as it is erected, a record of when each piece was erected could be maintained. This would help in updating CPM's, cost accounting, and productivity studies.

Inspection of the steel could also utilize this system. By scanning the bar code on the steel piece, the inspector would quickly determine which piece it is, confirm that it is in the correct location and that it has the correct dimensions. If the bar codes also identify what type of connections are to be made for that piece (i.g., what strength bolts, torque required, size of rivets, etc.) he could also quickly check this. By entering into the reader which pieces and connections he has checked, a record of his inspection would be immediately generated.

Warranty and Maintenance of Installed Equipment

It is frequently difficult to preserve records that are used for detailing maintenance and repairs performed on installed equipment. By attaching transponders to the equipment, this problem could be reduced. The transponder would contain the following information: name of supplier, manufacturer, and contractor who installed equipment, when it was installed, what the service requirements are, a listing of the repair parts and recommended spare parts inventory including part numbers and suppliers, any warranty work or repairs that were performed, and when the equipment was serviced and what was done during servicing.

Tool Control

This function would utilize a system similar to that of the material control system. When tools are received, the bar code on them would be scanned to determine storage location (The bar code would have to be put on the tool if it did not already have one). The storage bin would also have a bar code on it so that storage of the tool in the correct bin could be confirmed. When a tool is needed, a quick check of the database would determine the tool's location. A check could also be made to ensure that the person receiving the tools is authorized to do so. Thus this system would minimize the time required for storing and locating tools.

By attaching bar codes to the tools, a field inventory validation could be easily performed. It could quickly be determined who the tool was issued to, when it was issued, and when it is due back in the shop.

As an added benefit, the database could also be used to keep track of inventory levels, maintenance requirements, and who has what tools and when they are due back. Whenever inventories drop below specified levels, a report would be generated, including requisitions if desired, so that replacements could be ordered. Another report would provide details on the tools that have been issued. Finally, an additional report would identify what tools need to be serviced and what this servicing should include.

Material Movement Tracking

Keeping track of material on large projects can involve a lot of paperwork and manpower. This process could be simplified by using transponders to record the movements. For instance, transponders could be attached to scrapers and dump trucks. These transponders would contain information which would identify the vehicle and what it was hauling. When the tagged vehicle passed by a reader located adjacent to the road, the transponder would be activated and its information passed to the reader and then to the computer. Printouts could then detail when each vehicle passed by and

what cargo it was hauling. Similar applications could be used to track other materials.

One application of this information would be to determine what cycle times are. This is one of the key elements in productivity and simulation studies. Another use is to tally information on quantities put in place. For instance, when an asphalt truck leaves the batch plant, its weight could be recorded on the tag attached to the truck. As the truck passes the reader on the jobsite, it would be scanned and the weight recorded from the tag.

Vehicle Maintenance

Similarly to installed equipment, a transponder attached to a vehicle could provide a history of the maintenance and repairs that had been or were required for a piece of equipment.

Also, whenever a mechanic is performing repairs, a check of repair parts availability could quickly be made as long as the part identification number is known.

Worker Identification

Issuing workers identification cards with bar codes on them also has several construction applications. These cards could be used to monitor and control personnel access to the construction site, ensure that only authorized personnel receive materials and check out tools, and to help

maintain timecards. For instance, as each worker passes through the gate controlling access to the jobsite, he would pass his card through a bar code slot reader. As soon as all workers arrive, depart, or at any other time intervals, the information stored in the reader would be transmitted via a RF link to a computer. Querying this database would enable time cards to be updated and would identify who is and isn't on the job site. Payrolls and other personnel information could then be easily updated.

Identification of System Components

If bar codes have been attached to complicated system components such as those in HVAC systems, scanning them would quickly inform the user what a particular item was. It would also help him determine where in the system that item is to be located. Of course, it would also help in maintaining system component inventory status and receipt records as well as provide maintenance and service information.

Quality Control

By using interactive features of a RFDC system, the quality control inspector would identify what items are to be checked and what the checks should consist of. Querying the database would provide the inspector with specification requirements and other information such as manufacturer,

model number, style, etc. The system could also be used to record or log inspection information.

CHAPTER VI

IMPLEMENTATION CONSIDERATIONS

There are several selection decisions which must be considered before implementing a radio frequency data communication system. First, a license for the radio frequency used must be obtained from the Federal Communications Commission (FCC). FCC approval takes about 30 days. The equipment vendor will normally assist in obtaining this license. The license is authorized for only one location, and thus a new license must be obtained each time the equipment is moved to a new project site. However, if the company has a license for a low power frequency covering several locations for other communication systems, this license can sometimes be used.

Second, the range of the radio frequency link will vary from less than 1000 feet where obstructions exist to several miles in the open. Third, if a XT/AT computer is used, it must be dedicated to the RFDC system when it is in use. Mainframe computers will allow other simultaneous operations. Finally, wireless modems can be used to link computers together; their range is "line of sight".

How does a company implement a radio frequency data communication system? It must use careful planning. The wrong way is to buy the equipment and then seek a consultant to make the system work together.

Modern Materials Handling in 1987 ran a two-part series in which recommendations for implementing a system were made by a council of experts. A summary of these recommendations along with suggestions found in other technical journals is provided below.

Project Team Formation

First, a project team must be appointed. According to Knill, 1986, this should be made up of three personnel levels. The first level is representatives from each of the company's executive level departments. The next level is the venture manager. His responsibilities are to: "...oversee the work; bring the project in on schedule; bring the project in on budget; provide the project's visibility; set priorities; determine responsibilities." (MMH, 1987). The third level is the project manager who is to: "...design the system; develop specifications; schedule the system and select vendors; carry out the system's implementation and integration; oversee the start-up; review the system's performance." (MMH, 1987).

Analysis of Operations

An analysis of all company operations should follow. This will help the team members understand how each operation works independently and as a system. Some issues to consider include determining who needs what data and

when, how the information will be obtained, what the information will be used for after it is obtained, where tags/transponders will be placed on the target items, equipment requirements, environmental factors, and what implementation problems may develop. Because of the nature of the technology of bar coding, outside assistance during this phase is strongly recommended. Also, keep in mind that if bar codes are used, they are simply identifiers, similar to license plates or a Social Security number; information about the product is stored in the host computer's database which is accessible by the bar code (Knill, 1986). Next the team should evaluate the company's goals, including future plans. Specific milestones, including development of system specifications & economic justification, start-up schedule, training, and post-installation audit should be established. Also, system simulations can be run.

Economic Justification

An economic justification should be completed, even before selection of any equipment. This should continue through equipment selection, installation and start-up. Considerations should include how and how much the system will save and the performance reporting requirements and standards against which the system will be evaluated. Some of the typical benefits which should be evaluated include control of warehouse inventories, higher productivity of

individual workers, labor savings, shorter cycle times, higher worker morale, and improved customer relations.

Equipment Selection

The next step is equipment selection. In doing this it should be kept in mind that generally the best course of action is to think big, but implement in small steps. After one part of the plan proves itself, other areas can then follow.

At least one member of the team should become thoroughly familiar with the capabilities and requirements of the various equipment. This can be done by attending seminars, talking with other companies that have implemented a system or by talking with equipment suppliers and manufacturers.

One crucial item to consider when selecting equipment is the personnel who will operate it. Employees can be interviewed to determine what equipment attributes they feel would make their job easier. Other issues to consider include operator efficiency, need for operator mobility, weight of equipment (particularly hand-held equipment), and technical sophistication of the operators. Showing concern for the operators will also help in getting them to accept the new system.

System Startup

To ensure a smooth startup, the following 11-step plan was recommended (MMH, 1987):

- "Receive hardware and software,
- Put hardware in place,
- Check hardware operation,
- Load software,
- Check software operation,
- Initialize data base with information that will appear on each label,
- Conduct training sessions for all involved,
- Start up bar code system,
- Maintain system change log,
- Make freeze decision (i.e. decide that no further changes to the system will be made before full implementation), and
- Complete changeover to bar codes."

Details of each step including completion dates, individuals responsible, and step's requirements should be defined.

System Changes

The equipment vendor should be consulted before changes are made to the system. Keep in mind that although changes may improve efficiency, two types of added costs will be incurred. First is the cost of the equipment added or to

the software developed. Second is the delay incurred before the decision can be made to freeze the system and rely totally on that new system. Only when this occurs will the full benefits of the system be realized.

Training

Training is considered the most crucial step in implementing a system. Education should include every key member who is involved with the system. Training can start with a lecture and slide show to upper management followed by more detailed training for system operators. This lecture can include: "...reasons the system is needed and what it will do for the company, how the system will improve everyone's efficiency, and an overview of the hardware and software involved." (MMH, 1987). The training for the system operators should first include classroom settings where information such as details of individual equipment and how the entire system operates are conveyed. This should be followed by hands-on training so that the operators can become comfortable with it.

Following this, training should continue. This can include observation of operators by trainers and quizzes on system details. After the system has become operational, feedback should be solicited. Training of maintenance workers must also be considered. Finally, training sessions for new workers should be established.

System Audit

Finally an audit of the system should be completed. This should not simply be done after the system has become fully operational, but throughout the entire implementation process. Once the system has become fully operational, actual savings achieved should be measured against the old system and new system projections. Unanticipated savings/costs should be documented. Any bugs should be identified and eliminated. Refinements should be made as necessary.

Keep in mind that no system will become operational and immediately perform all functions desired. Problems will develop. That is why it is better to implement in steps.

In summary, to implement a system the following steps should be followed (Knill, 1986):

- "Use a project team.
- Appoint a strong leader for the team.
- Identify specific goals in advance.
- Involve users in the development.
- Design on a large scale.
- Implement manageable tasks.
- Pay attention to details and to the importance of components.
- Train, train, train."

Fraley (1984) also provides an excellent listing of detailed considerations. I have included some of these in Appendix B.

CHAPTER VII

CONCLUSIONS AND RECOMMENDATIONS

Radio frequency data communication systems will provide many benefits for a construction company. These benefits include labor savings, reduction of errors in computer databases, and quicker response time in providing information to those that need it. This is achieved through the use of radio frequency technology which allows real-time, interactive communication with a computer without being physically attached to that computer.

The primary items that make up a RFDC system include the bar code label/transponder, reader, computer interface unit and the computer system software.

In implementing a RFDC system a project team must be formed, an analysis of the company's operations conducted, economic justification completed, equipment selected, employees trained, and a system audit completed.

Radio frequency data communication systems have attained very limited adoption by the construction industry. One reason for this is that most RFDC systems used by other industries are in warehouse environments on items that are already bar coded. Construction applications frequently are for open jobsites and materials are seldom bar coded. Another problem is the lack of construction industry standards for RFDC use. These standards could include how,

when and where items would be marked or tagged and what information would be encoded in tags and transponders. Future research projects should demonstrate how systems work in a field environment and develop recommendations for standards. However, this should not deter executives from adopting the use of RFDC system technology for their own construction company in order to realize some of its proven benefits. Areas where benefits could be realized include material receipt, issue and cost control, steel erection operations, warranty and maintenance of installed equipment, tool control, material movement tracking, vehicle maintenance, worker identification, identification of system components, and quality control.

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APPENDIX B

RFDC SYSTEM APPLICATION CONSIDERATIONS

1. List all the areas that would lend themselves to RFDC system data capture.

2. From that list select one which is:
   - Relatively large;
   - Contains as many variables as possible.

This will provide an excellent foundation with minimal confusion.

3. Determine exactly what your goals are:
   - What is to be captured;
   - How it is to be captured;
   - What systems will serve you best.

4. Select a vendor(s) of equipment and review your objective. Emphasize interface and software - consider what support you will need.

5. Implement the test site.

6. Evaluate the test site:
   - employee cooperation;
   - read rates;
   - data flow;
   - report generation;
   - equipment reliability.

7. Adjust the operation to smooth out problems that may become apparent. This step may never be required, but the chances are good that at least small improvements are in order.

8. Expand into other sites and applications. With your experience gained from the test site the expansion should be quite smooth.

Source: Fraley, 1984